STATE OF CALIFORNIA
HIGHWAY TRANSPORTATION AGENCY
DEPARTMENT OF PUBLIC WORKS
DIVISION OF HIGHWAYS

FINDINGS FROM THE USE OF COMPENSATED SHRINKAGE PORTLAND CEMENT IN THE LODI FREEWAY EXPERIMENTAL PAVEMENT

A Study made by the
California Division of Highways
in cooperation with the
U.S. Department of Commerce,
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MATERIALS & RESEARCH DEPARTMENT

State of California
Department of Public Works
Division of Highways
Highway Transportation Agency

MATERIALS AND RESEARCH DEPARTMENT

June 1, 1965
Laboratory Project
Work Order 300259

Mr. J. C. Womack
State Highway Engineer
Division of Highways
Sacramento, California

Dear Mr. Womack:

Submitted for your consideration, is a report on:

Findings from the Use of

Compensated Shrinkage Portland Cement

in the Lodi Freeway Experimental Pavement

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Synopsis

An experimental portland cement concrete pavement section designed to evaluate concrete using a type of expanding portland cement referred to as "compensated shrinkage cement" was incorporated into a Central California highway project known as the Lodi Freeway, in the summer of 1963. This was the second project of its type; the first being on the Antelope Valley Freeway in the Southern part of the State in the spring of 1963. A complete report covering the first project titled "California Findings on an Experimental Pavement using Compensated Shrinkage Cement" was published in September, 1964.

The compensated shrinkage cement used on these projects was formulated to produce an expansion to offset or compensate for the drying shrinkage that normally occurs. The concrete in each of the six 1/4-mile units of the Lodi experimental pavement was placed monolithically with no expansion or contraction joints. Pavement end anchors were used in the compensated shrinkage cement units. The only discontinuities were the construction joints at the ends of the 1/4-mile units.

Related factors evaluated in conjunction with the use of the special cement were:

1. The effect of air entrainment

2. The effect of a moist earth blanket cure compared to polyethylene sheet cure

Evaluation of the behavior and the properties of concrete in the experimental sections was aided by the use of Carlson electrical strain gages embedded in the concrete, surface gage points, crack surveys, and testing of field fabricated test specimens.

Findings

1. The compensated shrinkage portland cements used on this project, the Antelope Valley Project, and that previously tested in the laboratory, all had similar expansive characteristics.

2. There was no significant difference in the cracking pattern of the Lodi experimental sections containing regular cement, as compared to those containing compensated shrinkage cement.

3. The effects of the two types of curing on development of cracking patterns and compressive strength were inconclusive.

4. The crack interval in the units containing air-entrained concrete was less (cracks closer together), than in comparable units without air entrainment.

5. The action of the compensated shrinkage cement during the moist curing period resulted in varying degrees of expansion in the three orthogonal directions. Expansion was greatest in the vertical direction and practically nil in the longitudinal direction. It appeared that the triaxial expansions varied inversely with the degree of restraint.

6. In this non-reinforced concrete pavement constructed using conventional procedures, no apparent benefits were achieved by the use of compensated shrinkage cement.

Introduction

This report is analogous to that published in September of 1964, which described work on a similar project, the Antelope Valley Freeway near Los Angeles(1)*. For the convenience of the reader, some of the same information is repeated here.

Recent developments in the portland cement industry have led to the manufacture of a cement with expansive properties which can be controlled within desirable limits, at least under laboratory conditions. The potential application of this new cement in concrete, is considered by some researchers to be quite extensive. For example, if a cement containing sufficient expansive component could be used in concrete to develop a force which would stress embedded high strength steel, it might compete in some areas with conventional prestressing methods. The cement for this type of application has been referred to as "self-stressing cement."

Expanding cement appeared to offer a possibility of constructing a non-reinforced concrete pavement without joints, which would have few, if any, transverse cracks. It was assumed that such pavements, in addition to being nearly crack-free, would be smoother riding because curling of short slabs due to differential drying shrinkage would be reduced or eliminated. Theoretically, in a monolithic slab structure, the tendency of the concrete to expand would be restrained by subgrade friction and special pavement anchors near the end of the slab, and would be manifested in the development of internal compressive stresses in the concrete during the curing period. Then, as the concrete contracted due to drying, compressive stresses would be reduced to near zero. Ideally, only small compressive stresses would remain.

The required amount of expansive component needed in the cement to just offset drying shrinkage was calculated to be less than that required for self-stressing operations. In non-reinforced pavement slabs, only enough expansion is needed to be equal to, or slightly greater than the contraction resulting from drying shrinkage. Preliminary studies as reported by Alexander Klein, Tsevi Karby and Milos Polivka(2) indicated that a cement having about 15% expansive component would be suitable for this type of work. This special cement will be referred to as "compensated shrinkage cement" in the remainder of this report.

Preliminary laboratory tests made by the Materials and Research Department on concrete using compensated shrinkage cement, while limited, were nevertheless encouraging. This work coupled

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* Numbers in parenthesis refer to list of references at the end of this report.

with that reported by others, such as the University of California[2,3] and the Concrete Research Corporation[4,5], led to the establishment of two experimental pavement sections on California highways. The first section is located on the Antelope Valley Freeway north of Los Angeles, road 07-LA-14. Findings on this first section were published in a California Division of Highways, Materials and Research Department report[1]. The second experimental section is located south of Sacramento on a freeway through Lodi, 10-SJ-99, and details are covered in this report.

Test Conditions

Principal features involved in the Contract Change Order incorporating this experimental work on the Lodi Freeway project, were as follows:

I. General

A. The experimental section was to consist of six 1/4-mile units with different mix designs. (Refer to the "As Constructed" plan of the test section, Figure 1, and the "Typical Pavement Cross-Section", Figure 1-A.)

B. Pavement containing compensated shrinkage cement was not to be placed within 200 feet of any structure that interrupted the continuity of paving.

C. Transverse weakened plane joints were not to be constructed within any of the units of the experimental pavement.

D. No interruption exceeding 18 hours was to occur between construction of any of the test units containing compensated shrinkage cement.

E. The end of any unit containing compensated shrinkage cement which terminated against pavement containing regular cement, was to be constructed with a pavement end anchor formed in the subgrade. An end anchor was also required at the end of any day's work containing the special cement.

II. Portland Cement

The compensated shrinkage cement was to have the same characteristics as that furnished to the Materials and Research Department for preliminary testing. (Job cement was Type II, conforming to the 1960 Standard Specifications.)

III. Curing

A. Units A, B, E and F were to be cured for 7 days with white polyethylene plastic sheeting 4 mils thick.

B. Units C and D were to be cured for 7 days with a 2-4-inch blanket of wet earth.

Construction Operations

The compensated shrinkage cement was delivered to the jobsite and handled in the same manner as the job specification cement. No problems were encountered in the mixing, placing, or finishing of the concrete with either of the two cements. Concrete was mixed on site in a Koehring Twinbatch 34E paving mixer and placed with a 24-foot side form paver.

For the experimental section, paving began at Unit A and proceeded through Unit F with each unit being paved on a different day. Pavement end anchors in the expanding cement units were constructed as shown in Figure 1. Although the 18-hour limit between paving of test sections was exceeded between Unit B and Unit C, the end anchorage system at the end of Unit B was adequate to restrain expansion of the concrete.

Units A, B, and C were paved with non-air-entrained concrete, and Units D, E, and F, with air-entrained concrete. Units A and F had a cement content of 5-1/2 sacks per cubic yard of job specification cement, and Units B, C, D, and E, contained 6 sacks of compensated shrinkage cement per cubic yard. The additional one-half sack of cement per cubic yard was considered necessary to restore the strength loss associated with the use of the special cement.

The concrete in Units A, B, E, and F, was cured with white polyethylene sheets, 4 mils in thickness, applied 4-6 hours after the concrete was placed. The delay in application was to allow the concrete to "set" sufficiently to prevent deformation by the plastic sheeting and the creation of smooth, slick surfaces on the pavement. To prevent excess surface evaporation during the delay period, the concrete was kept wet by a fog spray from water trucks. The plastic sheeting, 28 feet wide, was unrolled by hand and the edges were banked with lumber and earth. (See photographs.) The sheeting was removed at the end of the 7-day curing period.

Units C and D were cured by covering the pavement with an earth blanket, starting when the concrete was about 6 hours old. The material used was fine-grained sandy silt, taken from the median area adjacent to the pavement. A backhoe and a power shovel were used to place the earth on the pavement, but hand labor was necessary to spread the material to form a 2 to 4 inch blanket. This procedure was inefficient, and had longer units been involved, more suitable methods of distributing the earth would have been necessary. Some of the concrete was about 24 hours old before all the earth blanket was applied. The use of a water truck "around the clock" was required to keep the pavement surface wet until all the earth blanket was placed. The earth cover was then kept wet by subsequent application of water during the 7-day curing period. (See photographs.) At the end of the 7-day curing period, the earth was removed by a power grader, a broom, and water spray.

Testing Program

A program of testing and inspection was carried out by Materials and Research personnel with assistance from the Resident Engineer's forces. The program included batch plant inspection, accumulation of mix design data, cement and concrete sampling and testing, installation of Carlson gages and surface gage points with scheduled readings, the collection of miscellaneous weather data, and cracking surveys.

Actual unit strains and temperatures of the concrete in the test sections were determined by means of Carlson strain gages. These gages were placed near the longitudinal mid-point of the test units and at a distance of 3 feet from the outer edge of the pavement. (See Figure 1.) Where the Carlson gages were placed in a vertical position, it was necessary to excavate a shallow basin in the subgrade in advance of paving to accomodate their 10$\pm$-inch length, as the design thickness of the pavement was 8 inches. The gages oriented in a horizontal plane were located 4 inches below the surface of the concrete.

The gages and lead wires were placed on the subgrade in advance of the paving. A canvas was placed over the gages and nailed to the subgrade to prevent their displacement while the concrete was being dumped from the paver. After the paving machine had passed, the gages were dug out of the fresh concrete and set in the desired position. The excavated concrete was then carefully replaced and compacted. (See photographs.) The lead wires were extended to a reading station approximately 5 feet outside the shoulder line and an initial reading was taken. A predetermined schedule of strain readings was followed.

The surface gage points consisted of brass plugs, 3/4-inch in diameter and 2 inches long, placed in the fresh concrete 30 inches apart. Each plug had a 1/16-inch diameter hole drilled in the top for receiving the point of a dial gage extensometer. Three sets of gage plugs were installed in each of the six units for measuring the longitudinal movement of the slab. These were installed in groups of three, spaced about 50 feet apart, giving a total of 6 gage lengths per unit. In addition, 10 gage plugs (9 gage lengths) were placed in Unit D for measuring transverse movement. (See Figure 1.)

The gage plugs were installed by the use of templates made of steel strap, when the concrete was about 2 hours old. Initial readings could not be taken until the concrete was about 6 hours old when it was determined that the plugs were secure enough to support the weight and manipulations of the extensometer without movement. Measurements were made to 0.0001-inch over a 30-inch gage length and referred to a "standard bar" made of Invar steel.

To further evaluate the performance of the entire experimental section, profilograms and a series of cracking surveys were made.

Discussion

Carlson Gages

The Carlson strain gage data plotted versus time are shown in Figures 2 through 7. These curves show the temperature of the concrete and the unit strain. The "Indicated Unit Strain" curve was adjusted for thermal movements of the concrete, using an arbitrary coefficient of thermal expansion of 5.5×10^{-6} inches/inch/degree F. Thus, the "Adjusted Unit Strain" curves show the approximate net strain that can be attributed to the volume change caused essentially by the action of the expanding concrete. It will be noted that the major portion of the total expansion measured occurred within the first 24 hours after placement of the concrete.

The strain gage data obtained on this project correspond closely with those from the Antelope Valley Freeway project. In the compensated shrinkage cement units, the greatest amount of movement took place in the transverse and vertical directions. There was virtually no movement indicated in the longitudinal direction in any of the six units. No significant difference was noted in the expansion which took place in the air-entrained units as compared to the non-air-entrained units.

The vertical gage in Unit E was lost due to internal malfunction of the gage, but the other vertical gage (Unit D) indicated slightly less expansion than a similarly located gage on the Antelope Valley project. The transverse gages, on the other hand, indicate that a somewhat greater transverse expansion took place on the Lodi project.

Surface Gages

The longitudinally oriented surface gages indicated virtually no expansion which agrees with the Carlson gage data. The transverse surface gage expansion data obtained from Unit D was adjusted for thermal movements and is shown in Figure 8. Probable expansion curves are shown for both the Lodi and Antelope Valley projects. These curves indicate that considerably more transverse expansion took place at Lodi than at Antelope Valley. This condition was also noted, though to a lesser degree, in the data from transverse Carlson gages.

In the transverse direction, the unit expansion was greatest near the outer edges of the slab and least at the center of the slab. The tendency for expansion to take place is assumed to be uniform throughout the width of the slab, with the resistance to expansion being developed by subgrade friction. The frictional force that must be overcome for any expansion to take place in a transverse direction is maximum at the center of the slab and minimum at the edges.

Cracking Surveys

Probably the most meaningful evaluation of the effectiveness of the use of compensated shrinkage cement, can be made from a series of pavement surveys which showed the transverse cracking pattern that developed. The average distance between cracks was computed after each survey and a tabulation made which shows the development of the cracking. (See Table 1.) It can be seen that there is no appreciable difference in the crack interval in the units containing compensated shrinkage cement as compared to those units containing job specification cement.

Results of the later surveys show that more cracking occurred in the air-entrained units than in comparable non-air-entrained units. Generally, there was slightly less cracking in the wet earth cured sections containing compensated shrinkage cement as compared to the other two sections containing compensated shrinkage cement (B and D) which were plastic cured.

When compared to the Antelope Valley project, the average interval between cracks on the Lodi pavement is considerably greater at ages between two months and one year. At 28 days, the reverse was true. This apparent paradox is probably due to differences in weather conditions during and subsequent to pavement construction. The Antelope Valley project was paved during late May when cool and occasionally damp weather provided more nearly ideal curing conditions for the first 28 days. Between 1 month and 3 months, however, the maximum temperatures ranged from around 94°F to 108°F. On the other hand, the Lodi project was paved in early August and hot weather prevailed for about 2 months before cooler weather and rains set in. It appears that the ultimate cracking pattern will be approximately the same on both projects.

Profilograms

Profilograms of the Lodi experimental pavement were made with the truck-mounted Profilograph before the pavement was opened to traffic (in the fall of 1963), and again in February, 1965. There was no significant change in roughness development in any of the six experimental units during this period.

Miscellaneous

Tables 2 through 5 contain data on the cement, concrete, and aggregates. Tables 6 and 7 show weather conditions that prevailed during and after construction of the experimental units.

All the information derived from this project supports the conclusion made in the report on the Antelope Valley project; that in non-reinforced concrete pavement, no apparent benefits can be achieved by the use of compensated shrinkage cement.

The findings and conclusions reported herein, are based on observations and data collected and interpreted by the Materials and Research Department, California Division of Highways.

References

1. "California Findings on an Experimental Pavement Using Compensated Shrinkage Cement"
Materials and Research Laboratory Report,
September, 1964

2. "Properties of an Expansive Cement for Chemical Prestressing"
By Klein, Karby and Polivka,
Journal of the American Concrete Institute,
July, 1961

3. "Studies of Calcium Sulfoaluminate Admixtures for Expansive Cements"
By Klein and Troxell,
Proceedings, ASTM, Vol. 58, 1958

4. "Effects of Various Curing Conditions on Length Changes of Expansive Concretes"
Concrete Research and Development Corporation,
Van Nuys, California, September 10, 1962

5. "Expansive Cement Slabs on Grade"
Concrete Research and Development Corporation,
Van Nuys, California, January 31, 1963

TABLE I

LODI FREEWAY
EXPERIMENTAL PAVEMENT

AVERAGE CRACK INTERVAL IN FEET, BY UNIT

CURE	CEMENT	CEMENT FACTOR	AIR	UNIT	APPROXIMATE AGE, IN DAYS 10	14	28	42	175	322	452	620
PLASTIC	TYPE II	5½	NON-AIR ENTRAINED	A	123	90	71	71	71	71	59	37
PLASTIC	COMPENSATED SHRINKAGE CEMENT	6	NON-AIR ENTRAINED	B	130	93	62	62	54	54	48	30
WET EARTH	COMPENSATED SHRINKAGE CEMENT	6	NON-AIR ENTRAINED	C	300	86	75	75	67	63	57	39
WET EARTH	COMPENSATED SHRINKAGE CEMENT	6	AIR ENTRAINED	D	240	109	67	63	57	52	32	30
PLASTIC	COMPENSATED SHRINKAGE CEMENT	6	AIR ENTRAINED	E	125	96	83	69	59	54	30	21
PLASTIC	TYPE II	5½	AIR ENTRAINED	F	101	82	73	69	57	52	24	21

AVERAGE CRACK INTERVAL IN FEET, BY MIX CATEGORY

CATEGORY	APPROXIMATE AGE, IN DAYS 10	14	28	42	175	322	452	620
TYPE II CEMENT A & F	112	86	72	70	64	62	42	29
COMP. SHR. CEM. B,C,D & E	199	96	72	67	59	56	42	30
NON-AIR ENTRAINED A,B & C	184	90	71	71	64	63	55	35
AIR-ENTRAINED D,E & F	155	96	74	67	58	53	29	24
COMBINED ALL	170	93	72	68	61	58	42	30
PLASTIC CURED, COMP. SHR., B & E	128	95	73	66	57	54	39	26
EARTH CURED, COMP. SHR, C & D	270	98	71	69	62	58	45	35

Table 2

REPORT OF TESTS ON PORTLAND CEMENT

Specifications		Lodi Project: Type II, Low Alk. Avg. of 3 Tests	Lodi Project: Compensated Shrinkage Cement Avg. of 8 tests	Antelope Valley Project: Compensated Shrinkage Cement Average of 8 Tests
SiO_2 %	21.0 Min.	23.0	22.2	20.7
Al_2O_3 %	6.0 Max.	4.7	4.9	5.7
Fe_2O_3 %	6.0 Max.	2.7	2.7	2.4
CaO %		65.4	64.8	63.8
MgO %	5.0 Max.	1.5	0.8	2.1
SO_3 %	2.5 Max.	1.68	3.24	3.51
Ig. Loss %	3.0 Max.	0.56	0.73	1.17
Insol. Res. %	0.75 Max.	0.28	1.12	0.44
NA_2O %		0.24	0.23	0.17
K_2O %		0.30	0.23	0.39
Equiv. NA_2O %	0.60 Max.	0.44	0.39	0.43
C_4AF %		8.00	8.00*	7.00*
C_3A %	8 Max.	8.00	9.00*	11.00*
$CaSO_4$ %		3.00	6.00*	6.00*
C_3S %		51.00	48.00*	51.00*
C_2S %		27.00	27.00*	21.00*
COMPRESSIVE STRENGTH PSI				
3 Days	1000 Min.	2410	2022	2144
7 Days	1800 Min.	3895	2876	3100
SURFACE AREA BLAINE CM²/G	2800 Min.	3392	3176	3414
AUTOCLAVE EXPANSION %	0.50 Max.	+0.075	+4.73	6.9
(1)				
(2)				
(3)				
INITIAL SET GILMORE HRS: MIN.	0:60 Min.	3:08	2:75	2:01
FINAL SET HRS: MIN.	10 Hr. Max.	4:50	4:28	4:03
AIR CONTENT %	12.0 Max.	9.0	8.6	8.8
EXPANSION	0.010 Max.	Test method not suitable		
CONTRACTION	0.048 Max.	0.040	0.042**	0.062**

Remarks:

* Calculated compounds for compensated shrinkage cement have questionable meaning.

** For the Antelope project, compensated shrinkage cement mortar bars were removed from molds at 6 hours. On the Lodi project, the bars were removed at 24 hours.

Table 3

Typical Grading and Aggregate Information

Typical Aggregate Grading as Used

Sieve Size	Percent Passing Sieves: Combined Grading	Percent Passing Sieves: Specifications
2"	100	100
1-1/2"	100	90 - 100
1"	67	50 - 86
3/4"	51	45 - 75
3/8"	42	38 - 55
No. 4	39	30 - 45
8	33	23 - 35
16	27	17 - 31
30	18	10 - 21
50	9	4 - 13
100	3	1 - 4
200	1	0 - 2

*The passing No. 4 fraction was adjusted slightly for the air-entrained concrete mixes and for change in the cement content.

Aggregate Information

Source: Mokelumne River near Clements

Petrographic Analysis:

Coarse: Quartzite, volcanic, sandstone, meta sandstone, schist, gneiss, granitic (diorite-gabbro) with traces of hornfels, ultrabasics, granitics, and quartz

Fine: Quartz, quartzite, granitic volcanic, sandstone, meta sandstone, schist, with traces of ultrabasics and biotite.

Typical Test Data:

Sodium Sulfate Soundness Loss:	Less than 4%
Coarse Aggregate Cleanness Value: (Test Method No. Calif. 227)	Average, 82 (Spec. 75 min.)
Sand Equivalent: (Test Method No. Calif. 217	Average, 85 (Spec. 75 min.)
Specific Gravity (SSD):	Coarse, 2.68; Fines, 2.62
Absorption, %:	Coarse, 1.2 ; Fines, 2.0

Table 4

Average Results of Tests on Fresh Concrete

Unit and Mix	Cement Type	Kelly Ball Slump, Ins.*	Air %	Unit Wt. Lbs./CF	W/C Lbs./Sk.	Cement Factor Sks/CY
A - 5-1/2 Sk.	II	1.5	1.6	150.7	44.5	5.27
B - 6-sk., Non-AE	CSC	2.0	2.0	149.3	42.9	5.74
C - 6-sk., Non-AE	CSC	1.5	1.9	149.2	42.7	5.88
D - 6-sk., AE	CSC	2.0	3.6	147.3	39.3	5.92
E - 6-sk., AE	CSC	1.8	3.8	147.0	40.6	5.79
F - 5-1/2 sk., AE	II	2.0	3.0	148.7	42.4	5.41

CSC - Compensated shrinkage cement

*Test Method No. Calif. 520

Table 5

Summary of Test Results on Hardened Concrete

Unit	6x12" Cylinders Average of 6		5" Diameter Cores Average of 5	Flexural Strength, psi 6" x 6" x 20" Beams Average of 4
	14-day	28-day	60-day	14-day
A 5-1/2 Sk., II, Non AE	2400	3740	4690	565
B 6-Sk., CSC, Non-AE	2330	3740	4510	510
C 6-Sk., CSC, Non-AE	2260	3560	4730	545
D 6-Sk., CSC, AE	2200	3430	3940	495
E 6-Sk., CSC, AE	2230	3260	3980	465
F 5-1/2-Sk., II, AE	2250	3400	4130	545

Table 6

Climatological Conditions During Curing Period

Date, 1963	Time	Wind Vel. MPH	Rel. Hum. %	Evaporation Rate, Ml/Hr.	Ambient Temp. °F*	Weather Station Record Min. °F	Weather Station Record Max. °F
8-1	1000	4-8	59	2	72	59	91
	1200	4-8	46	7	82		
	1400	4-8	34	9	100		
	1600	2-4	28	11	108		
	1800	3-4	30	10	96		
	2000	6-7	42	5	78		
8-2	0900	5-6	73	1	63	54	90
	1130	5-6	43	6	82		
	1330	5-7	38	8	90		
	1530	4-6	37	11	91		
	1730	2-5	38	10	88		
	1930	3-5	46	8	76		
8-3	0700	0-2	76	0	58		
	0900	3-6	61	1	68		
	1100	2-4	47	5	79		
	1300	---	--	7	--		
	1500	---	--	11	--		
	1700	---	--	10	--		
	2000	---	--	7	--		
8-5	0900	0-2	48	2	76	50	95
	1100	2-3	39	5	88		
	1300	3-4	35	9	95		
	1500	2-4	29	13	102		
	1630	4-6	27	11	104		
	1900	3-7	44	10	88		
8-6	1000	3-5	--	6	--	57	97
	1200	5-7	41	12	85		
	1600	4-6	30	22	99		
	1800	3-5	26	13	97		
	2000	3-5	44	10	86		
8-7	0900	3-5	60	2	72	59	93
	1100	5-7	40	6	90		
	1500	0-2	29	14	108		
	1800	3-5	32	15	95		
8-8	0900	0-2	49	3	77	64	85
	1400	5-8	31	14	100		
	1530	5-7	34	11	90		
	1800	5-7	39	6	85		
	2030	0	53	4	74		

Continued

Table 6
Climatological Conditions During Curing Period

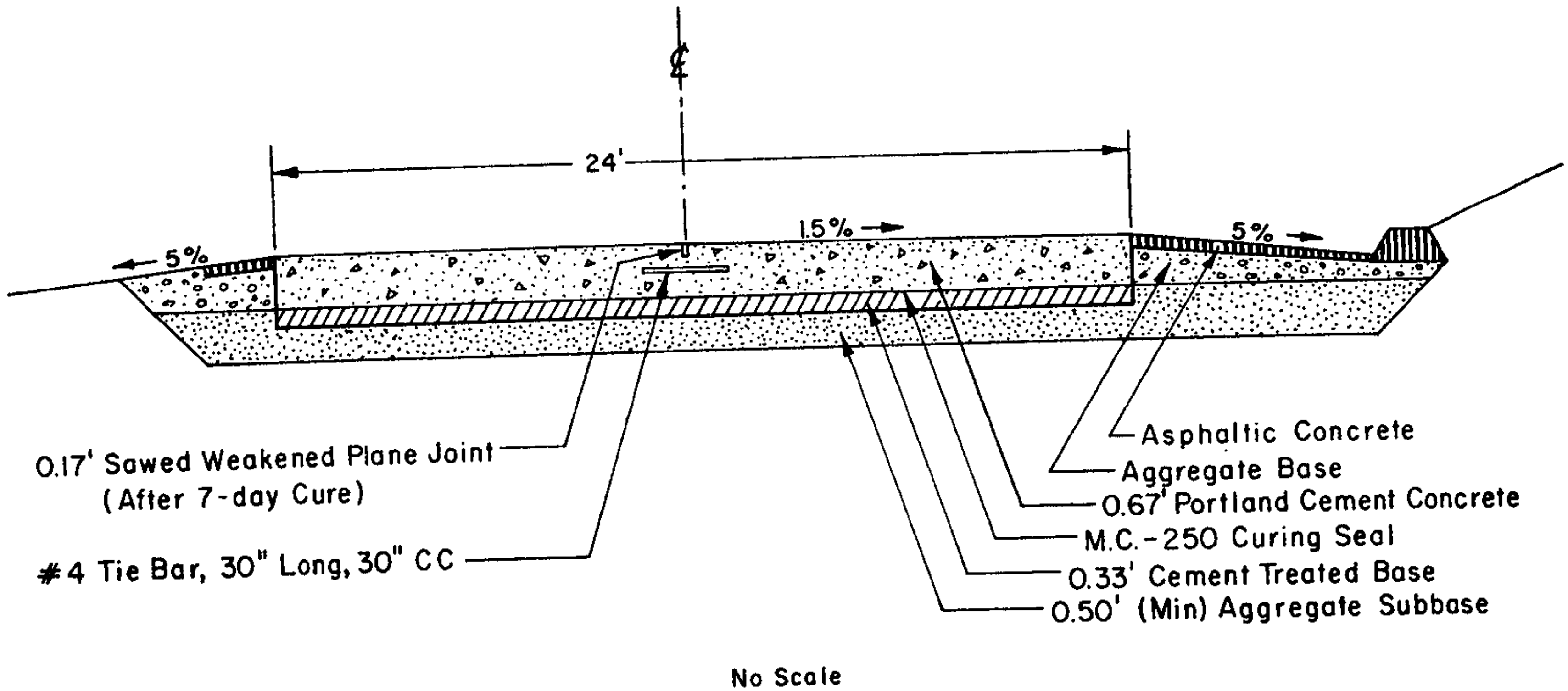
Date, 1963	Time	Wind Vel. MPH	Rel. Hum. %	Evaporation Rate, Ml/Hr.	Ambient Temp. °F*	Weather Station Records Min. °F	Weather Station Records Max. °F
8-9	0900	0-2	47	2	81	64	93
	1100	0-2	43	9	86		
	1300	0-2	38	15	92		
	1600	2-4	32	11	102		
	1800	3-5	34	12	98		
8-10	0900	3-5	45	3	80	64	93
	1100	3-5	42	9	94		
	1300	3-5	34	12	96		
	1500	4-6	31	10	104		
	1800	---	--	7	---		
8-12	0800	0-2	62	1	68	62	92
	0930	2-3	51	2	77		
	1030	4-7	44	8	84		
	1230	4-7	38	13	92		
	1430	4-6	32	20	100		
	1800	---	--	20	---		
	2000	---	--	16	---		
8-13	0700	0-2	83	0	56	61	93
	0900	2-5	51	4	75		
	1200	---	--	13	--		
	1500	---	--	15	--		
	1800	---	--	25	--		
8-14	0630	0-2	73	0	56	62	98
	0930	2-4	51	6	75		
	1030	2-4	42	9	86		
	1200	---	--	10	--		
	1500	---	--	20	--		
	1630	---	--	23	--		
8-15	0600	0-2	70	0	58	63	100
	0800	0-2	65	2	67		
	1000	0-2	38	7	88		
	1200	---	--	11	--		
	1500	---	--	22	--		
	1600	---	--	26	--		

*Measured approximately 1 foot above ground near pavement slab.

Table 7

Climatological Conditions After Initial 7-day Curing Period

Date, 1963	Time	Wind Vel. MPH	Rel. Hum. %	Evaporation Rate, Ml/Hr.	Ambient Temp. °F	Weather Station Records Min. °F	Weather Station Records Max. °F
8-16	0600	0	85	0	54	62	96
	0900	0-2	49	4	75		
	1030	2-4	45	8	82		
	1200	---	--	9	--		
	1500	---	--	17	--		
	1700	---	--	23	--		
8-19	0600	0	88	0	52	59	93
	0900	0-2	58	3	71		
	1100	4-7	42	8	84		
	1400	---	--	15	--		
	1700	---	--	24	--		
8-20	0900	0-2	55	4	71	60	94
	1200	---	--	14	--		
	1400	---	--	19	--		
	1530	---	--	23	--		
8-22	0700	0-2	92	1	56	60	93
	1100	0-2	43	6	84		
	1400	---	--	14	--		
	1730	---	--	17	--		
8-26	0830	0-2	58	--	67	59	92



TYPICAL PAVEMENT CROSS SECTION

CARLSON GAGE DATA — LODI FREEWAY

EXPERIMENTAL SECTION (UNIT A)

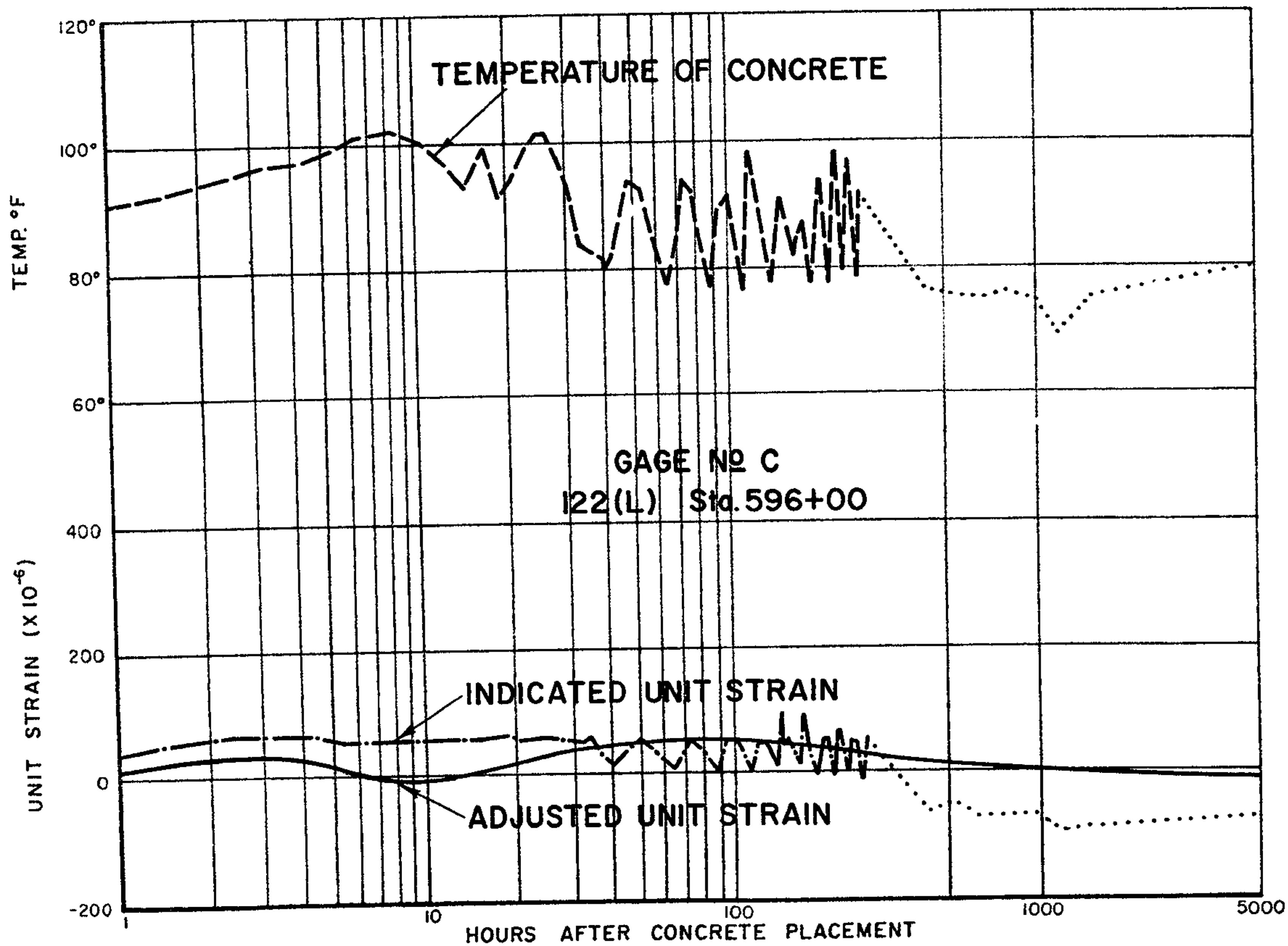


FIGURE 2

CARLSON GAGE DATA — LODI FREEWAY

EXPERIMENTAL SECTION (UNIT B)

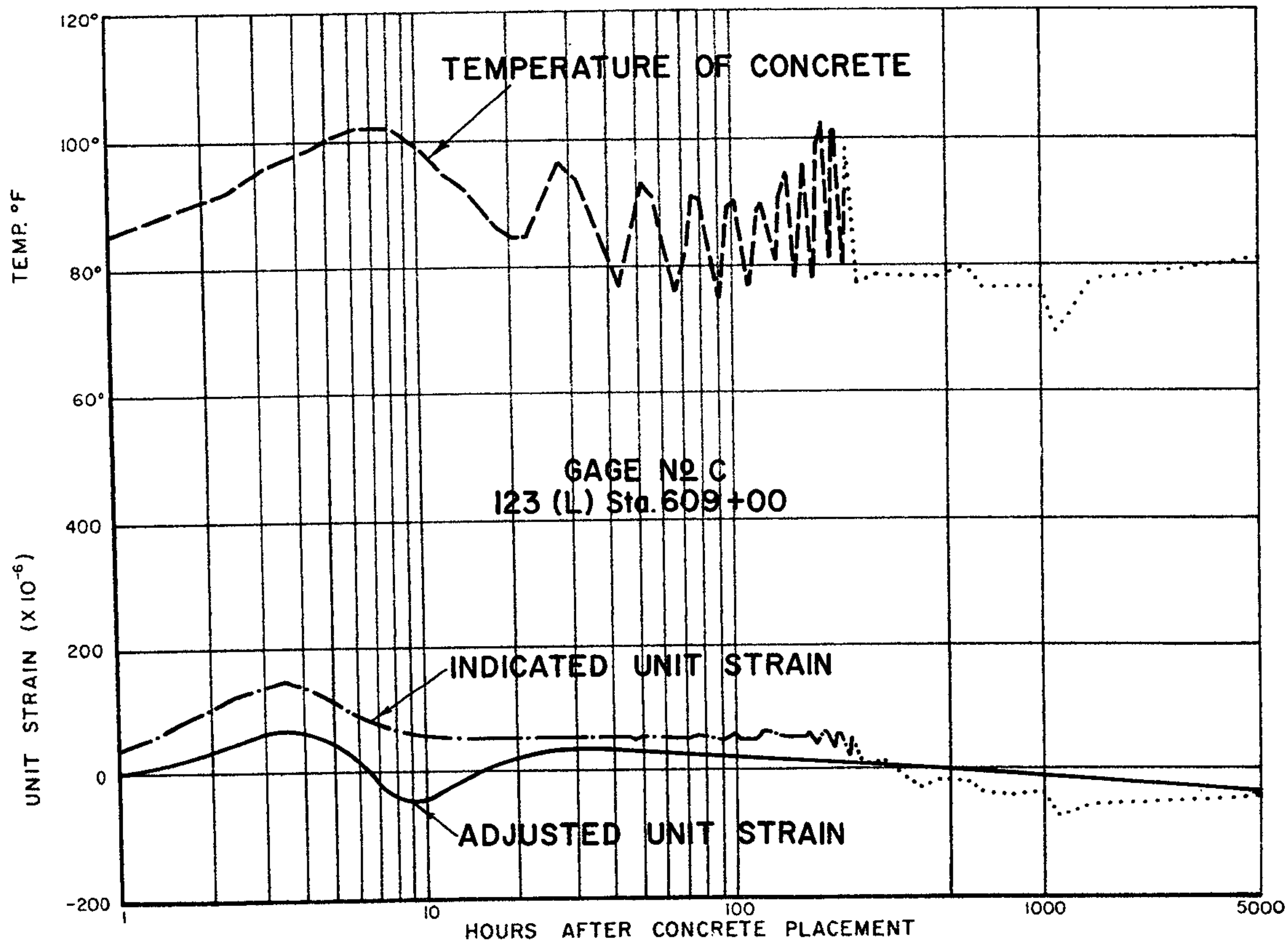
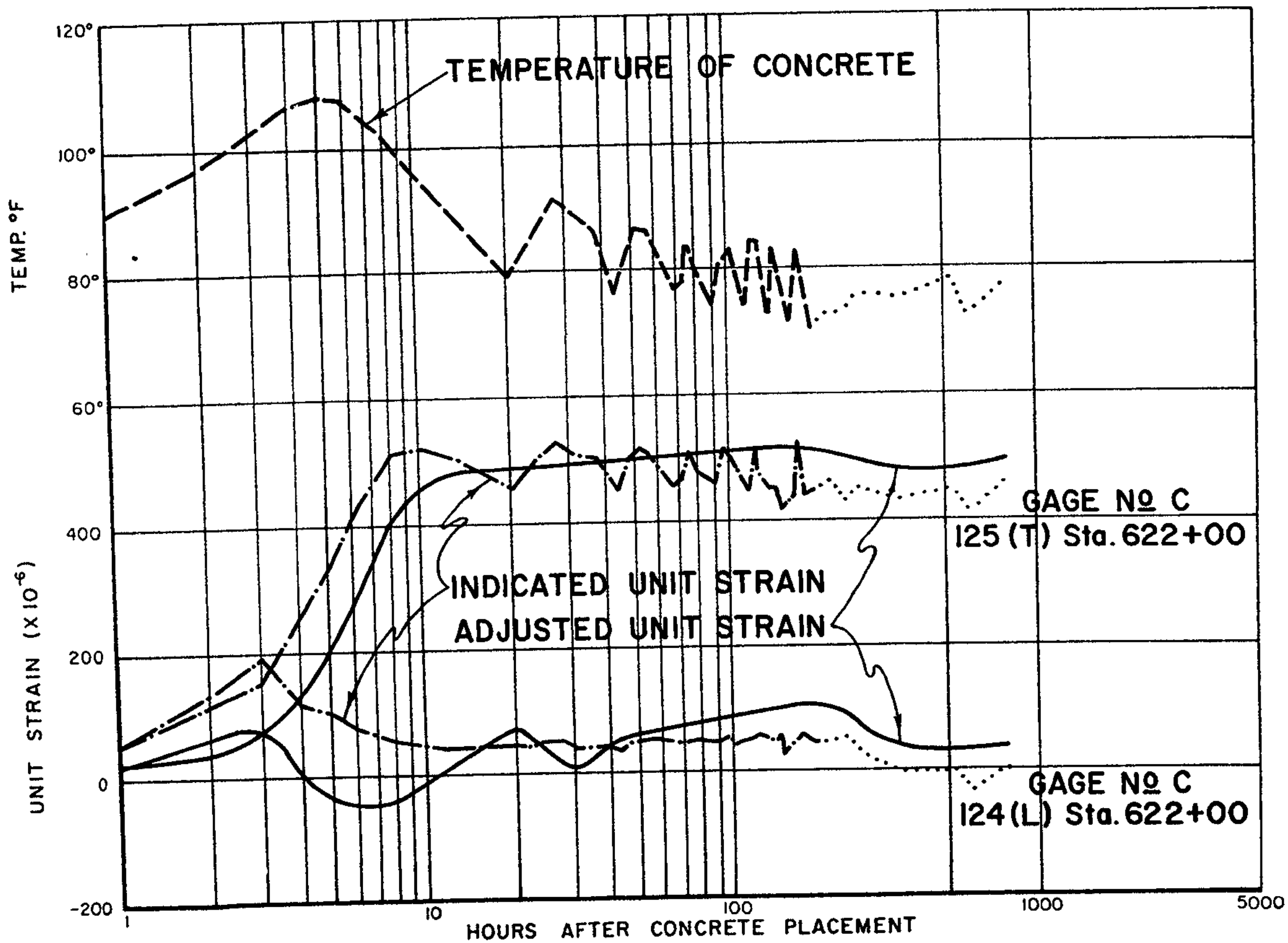


FIGURE 3

FIGURE 4

CARLSON GAGE DATA — LODI FREEWAY

EXPERIMENTAL SECTION (UNIT C)



CARLSON GAGE DATA – LODI FREEWAY

EXPERIMENTAL SECTION (UNIT D)

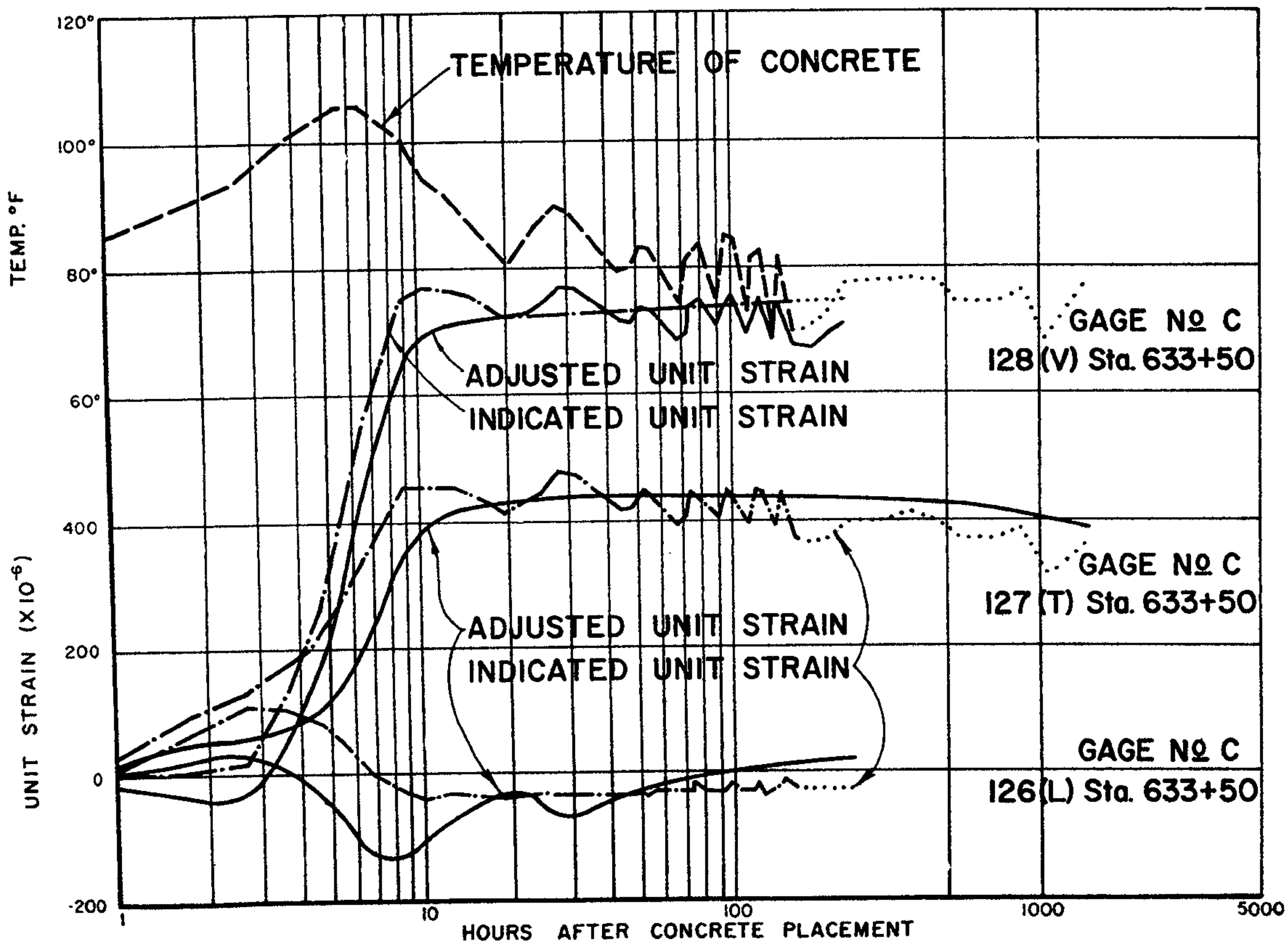


FIGURE 5

CARLSON GAGE DATA — LODI FREEWAY

EXPERIMENTAL SECTION (UNIT E)

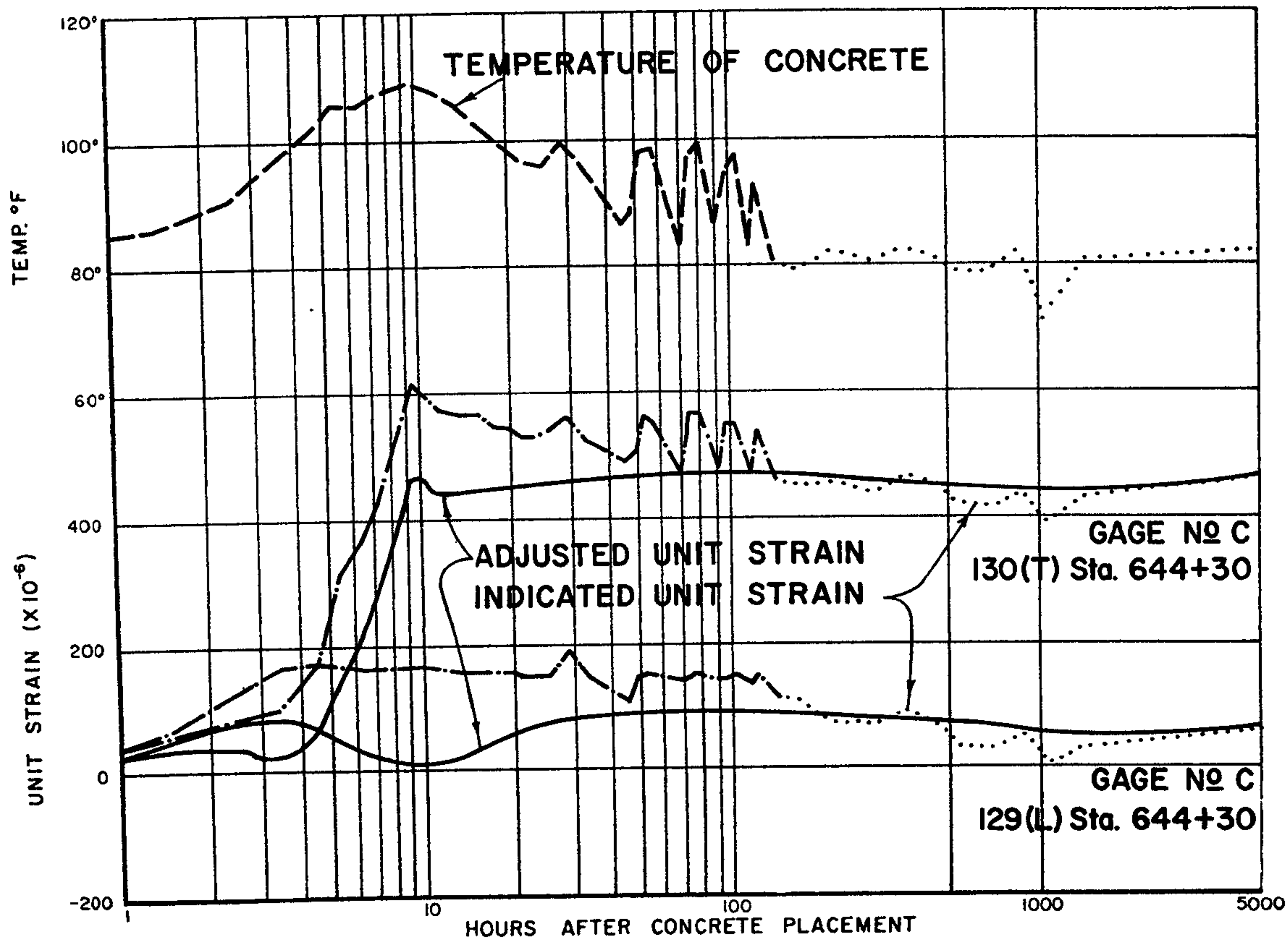


FIGURE 6

CARLSON GAGE DATA — LODI FREEWAY

EXPERIMENTAL SECTION (UNIT F)

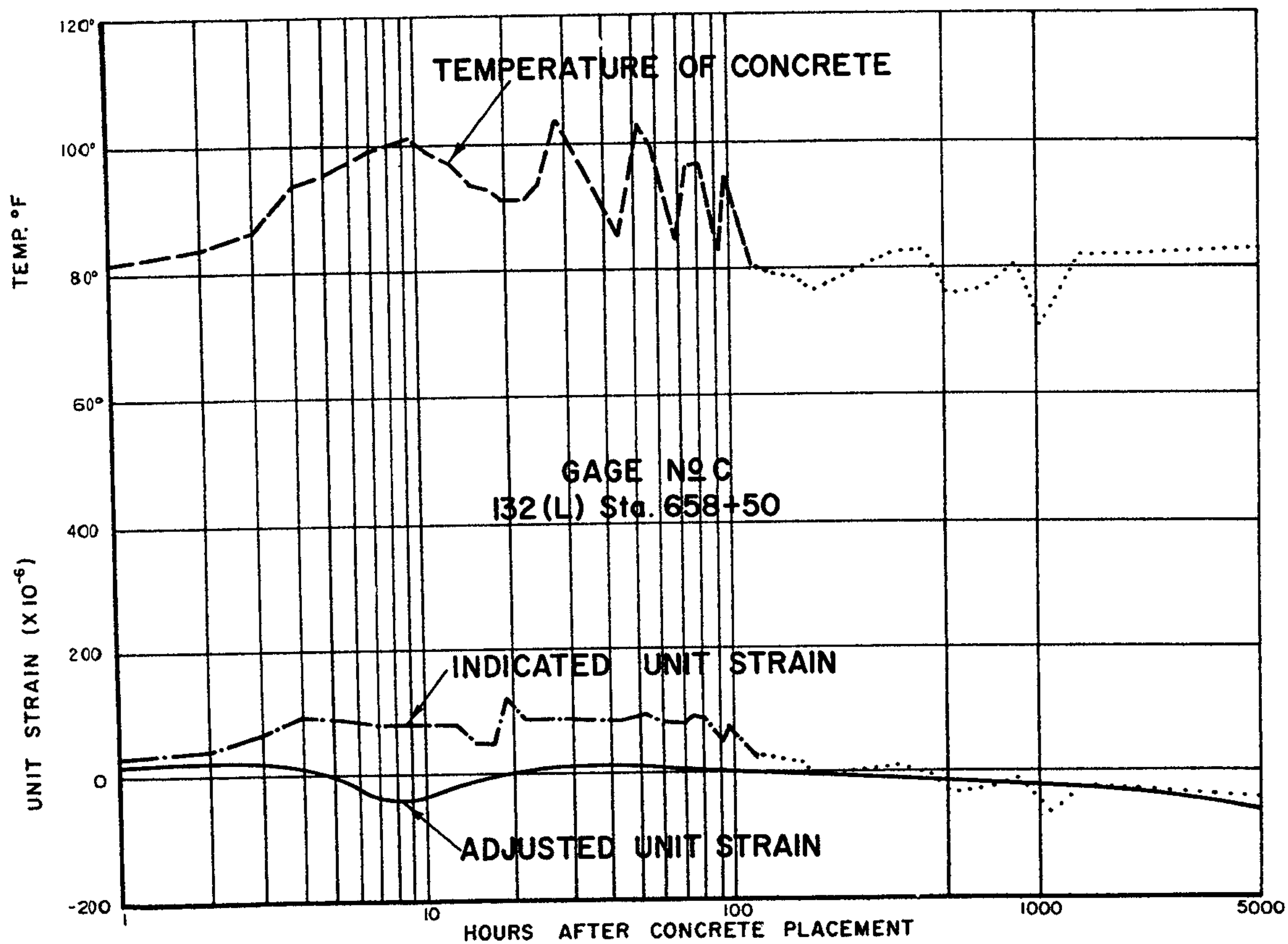
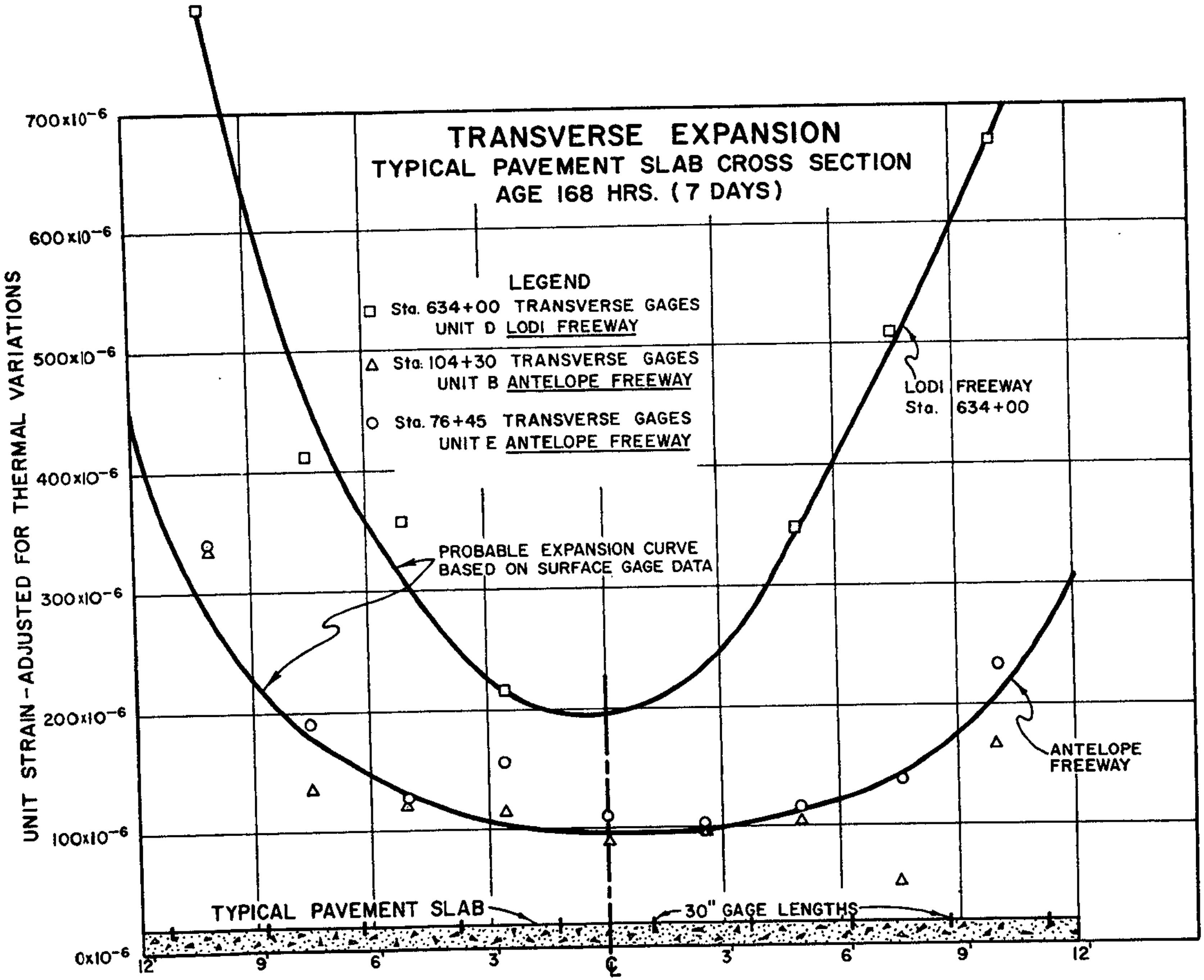


FIGURE 7

Figure 8

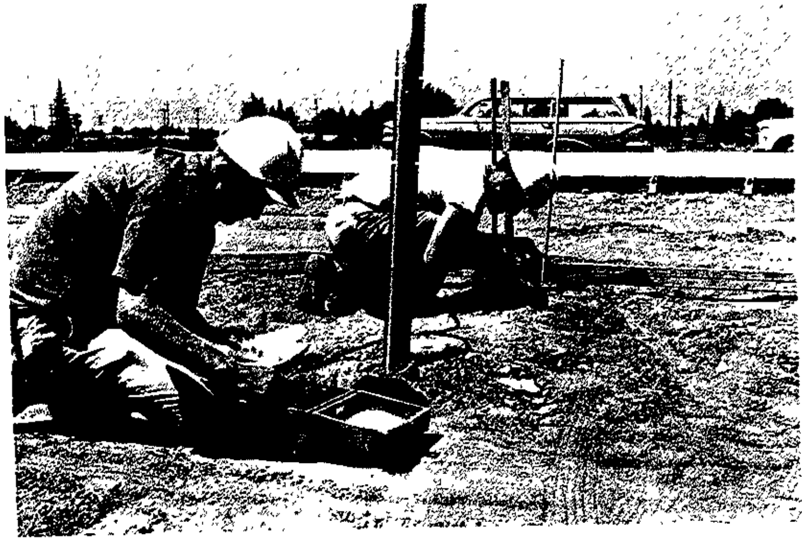


TRANSVERSE EXPANSION
TYPICAL PAVEMENT SLAB CROSS SECTION
AGE 168 HRS. (7 DAYS)
LEGEND
Sta. 634+00 TRANSVERSE GAGES UNIT D LODI FREEWAY
Sta. 104+30 TRANSVERSE GAGES UNIT B ANTELOPE FREEWAY
Sta. 76+45 TRANSVERSE GAGES UNIT E ANTELOPE FREEWAY
PROBABLE EXPANSION CURVE BASED ON SURFACE GAGE DATA
LODI FREEWAY Sta. 634+00
ANTELOPE FREEWAY
TYPICAL PAVEMENT SLAB
30" GAGE LENGTHS
UNIT STRAIN - ADJUSTED FOR THERMAL VARIATIONS
700x10⁻⁶
600x10⁻⁶
500x10⁻⁶
400x10⁻⁶
300x10⁻⁶
200x10⁻⁶
100x10⁻⁶
0x10⁻⁶
12'
9'
6'
3'
℄
3'
6'
9'
12'

1. Placement of Carlson strain gages in subgrade trench for protection

2. Close-up of Carlson gages

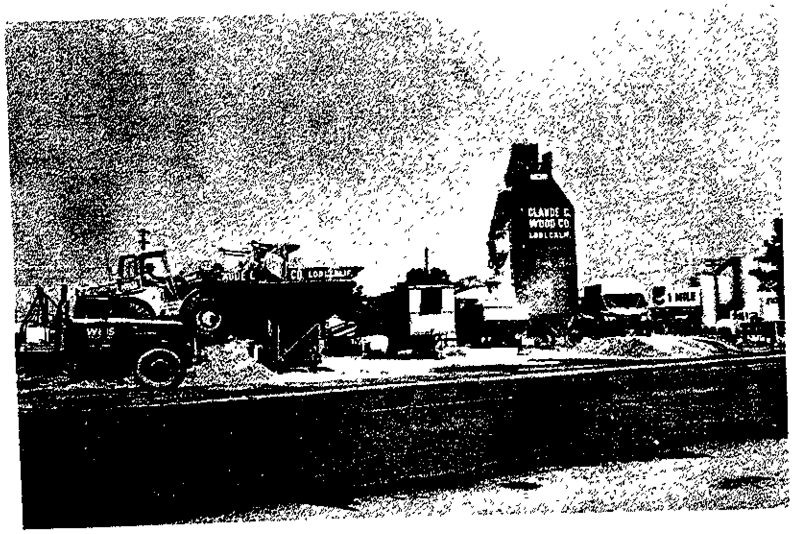
3. Orientation of longitudinal and transverse Carlson gages after concrete placement



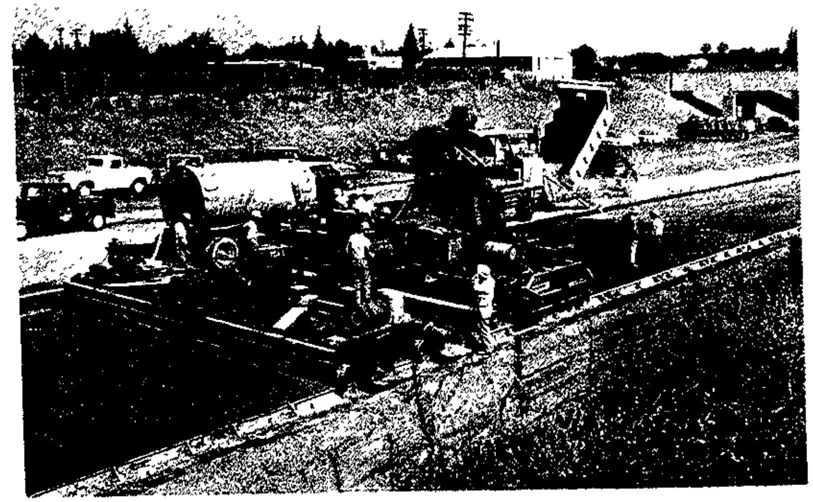
4. Engineers obtaining Carlson strain gage and thermocouple measurements

5. Positioning of longitudinal surface gage plugs for 30-inch extensometer measurements

6. Engineers obtaining extensometer measurements at a longitudinal surface gage installation

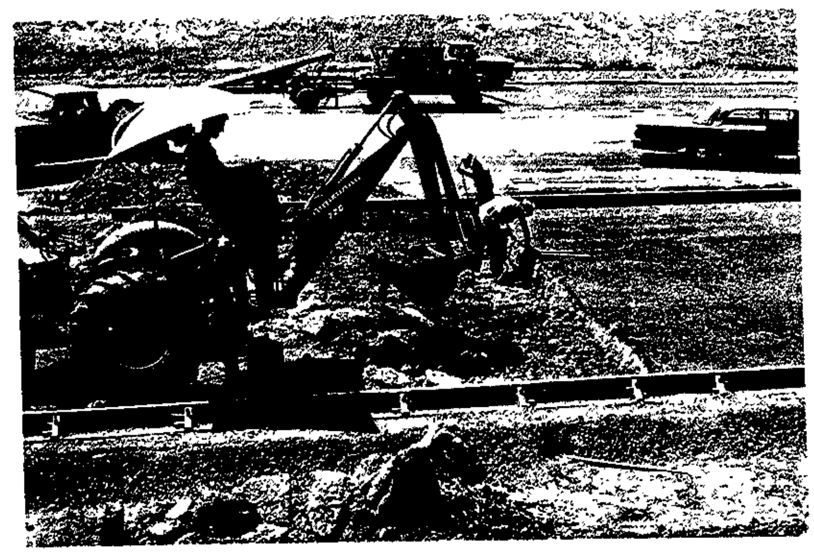


7. Portable batch plant used in conjunction with permanent installation

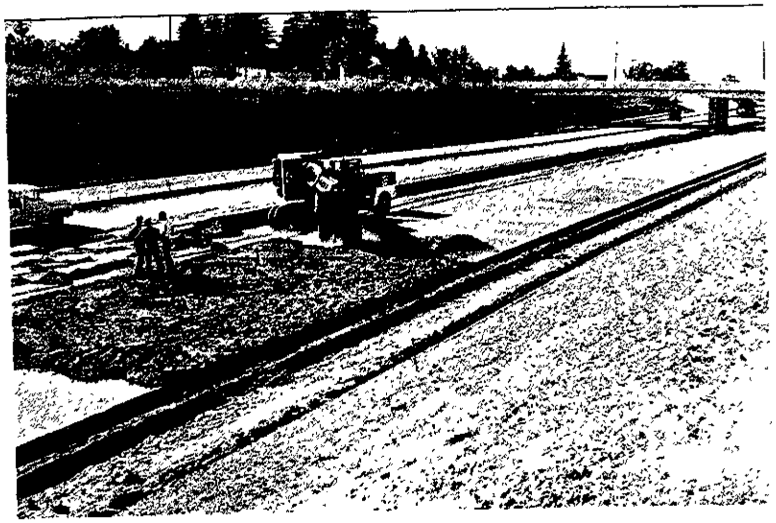


8. Paving operation

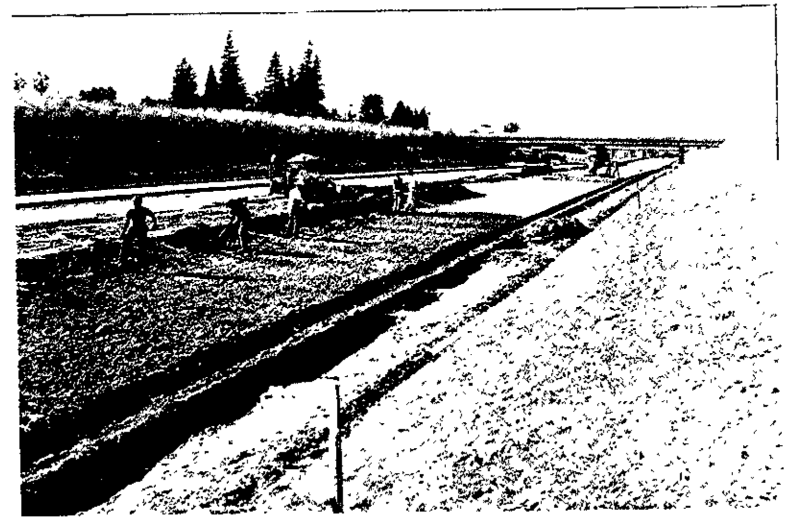
9. Looking south along experimental section



10. Excavation for pavement end anchor at the conclusion of a day's run



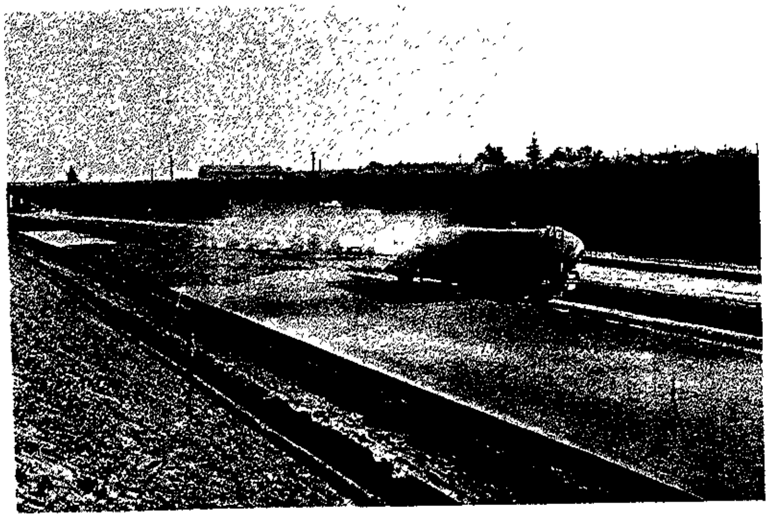
11. Beginning of earth cover placement on Unit C



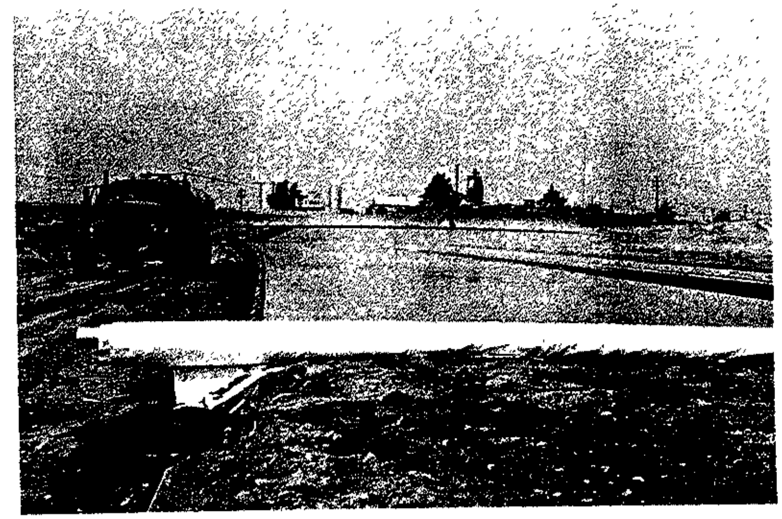
12. Distribution of earth by hand

13. Looking south at earth covered Units D and C

14. Watering of earth blanket

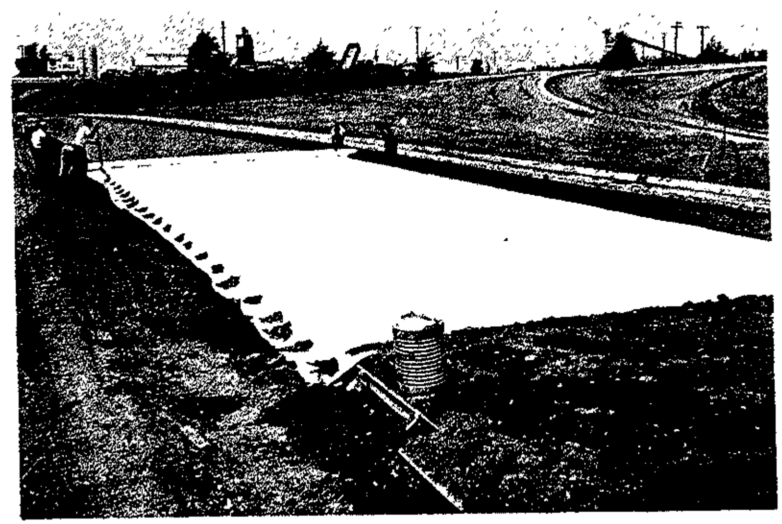


15. Fog spraying of pavement prior to covering with earth or plastic



16. Fog spray prior to covering with white polyethylene plastic sheeting for curing

17. Beginning of polyethylene covering operation



18. Continuation of covering operation with earth placement along edges